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MAGNETIC TUNING AND INSTALLATION MODIFICATIONS OF UNDULATOR U48 FOR THE DELHI LIGHT SOURCE (DLS)*

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Abstract

A compact THz radiation facility based on the principle of a pre-bunched Free Electron Laser, called Delhi Light Source (DLS) is at the final stage of commissioning at IUAC, New Delhi, India. For generation of THz radiation in DLS, an undulator with period length of 48 mm (U48), built by HZB and refurbished at DESY will be used. The magnetic tuning and the field measurements have been done on the U48 along with the design and installation of correction coils at the entrance/exit of the U48. In addition, horizontal and vertical ambient field correction coils were integrated into the magnet girders. A quadrupole correction coil along the vacuum chamber in order to mitigate the defocusing effect of the U48 on the electron beam has been designed. The current through all coils has been adjusted as a function of the gap by the new control system designed for the U48. In addition, an extruded aluminium vacuum chamber was designed and fabricated and will be aligned with the the undulator soon.

INTRODUCTION

A pre-bunched Free Electron Laser facility called Delhi Light Source (DLS) is in the final stage of commissioning at the Inter University Accelerator Centre (IUAC). In this project, radiation from electrons wiggling inside the undulator will be produced in the frequency range of 0.18 to 3 THz [1, 2]. The parameters of the required undulator for this purpose were optimized with the help of Radia software [3] in the past [4]. The U48, originally built by HZB as a modulator for a HGHG-FEL testbed at MAX-Lab was in match with the optimized parameters and donated to IUAC for its use in DLS. The magnetic field measurements were done with a Hall probe and a stretched wire setup at HZB and DESY, respectively. In this paper, the results of magnetic measurements along with a few modifications done on the undulator are reported. The first section discusses modifications done to the end pole configuration of the undulator. This is followed by the results of the hall probe and stretched wire measurements. Implementation of various coils for the correction of residual field integrals, the earth field and the defocusing effects of the undulator are discussed along with the details on the fabrication of the extruded vacuum chamber. The last sections describe the characteristics of the control system specifications and the current status of the device. Table 1 summarizes the specifications of the U48 which is now to be installed in the DLS beamline.

Table 1: Specifications of U48 to Be Installed in DLS

Specification	Details
Undulator Technology	Pure Permanent Magnet
Configuration	Antisymmetric
Magnet material	NdFeB (B_r=1.2 T)
Undulator period length	48 mm
Number of periods	32
Magnetic field direction	Horizontal (90° rotated)
Magnet dimensions	70 x 12 x 22 mm^3
Undulator working gap	16 - 45 mm
Magnetic Field	0.6 -0.1 T

MODIFICATION OF END DESIGN

The original magnetic end design of the U48 with half "B" magnet (+0.5; -1 end configuration) results in a substantial gap- dependent offset in the electron beam trajectory with which the device could not be operated at such a low electron energy. Additional half "A" magnet was used to shift trajectory back on-axis (-0.25; +0.75; -1 end configuration). A miniature model of the undulator, magnetic field and trajectory gap dependence before and after the modification in end termination are shown in Fig. 1.

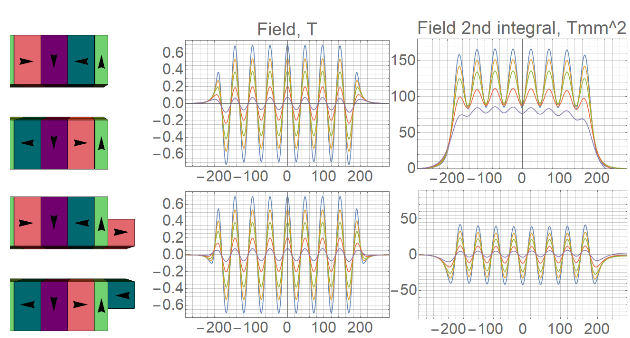

Figure 1: End field termination before (top) and after (bottom) modification, magnetic field and trajectory along beam direction [mm] for various gaps.

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HALL PROBE MEASUREMENTS

Hall probe measurements were performed at HZB to validate the magnetic performance of U48 and to analyse the necessity of additional magnetic shimming. Figure 2 shows the U48 at the Hall probe bench. The results of the magnetic field measurements are shown in Figs. 3 and 4 for different gap values.

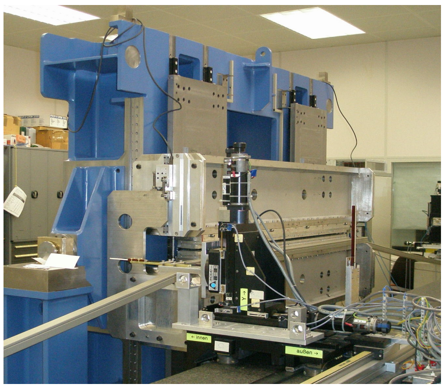

Figure 2: U48 at hall probe measurement bench.

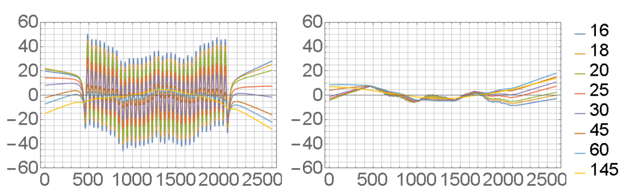

Figure 3: Vertical and horizontal second field integrals [Tmm^2] along the beam direction [mm] for different gaps.

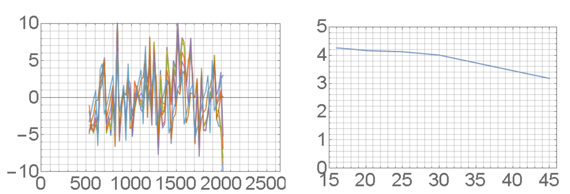

Figure 4: Phase error [deg] along the beam direction [mm] for different gaps and phase error RMS as function of gap [mm].

STRETCHED WIRE MEASUREMENTS

The measurement of the magnetic field integrals of the U48 in order to characterize its performance with the electron beam in the beamline have been performed by a stretched wire setup.

Setup

For the measurements on the U48, a wire of a CuBe alloy was stretched between two supports at both ends of the device. The position of wire was changed with the help of linear stages controlled by a Newmark motion controller (Fig. 5). An ADS1263EVM ADC board by Texas Instruments was used to measure the voltages induced when the wire is moved. A LabVIEW based software was made to control the linear stages, to collect the digitized voltage signals and finally convert them into field integral values.

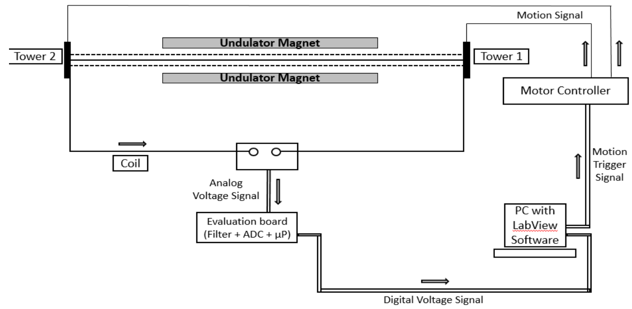

Figure 5: Stretched wire setup.

Measurements and Results

The measurements were performed with a step size of 1 mm for both the vertical and horizontal field integrals, respectively. These measurements were done at various undulator gaps ranging from the minimum working gap of 16 mm to the open gap of 140 mm. Referring to Fig. 6, one can conclude that the non-zero field integrals need to be compensated by the use of correction coils. Based on the measurements of 1st and 2nd field integrals, a gap dependent table of current setpoints has been generated for correction of both residual kick and displacement errors. These tables have been implemented to the control system.

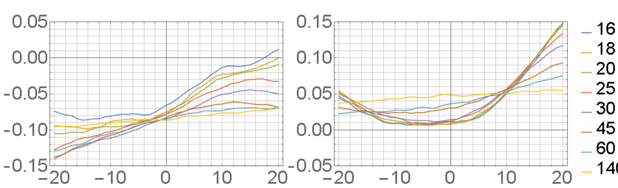

Figure 6: Multipoles, i.e. vertical and horizontal 1st field integrals [Tmm] as function of transverse position [mm] for various gaps [mm].

CORRECTION COILS

The modification of the magnetic termination already led to an improvement of the gap dependent trajectory offset and kick on the electron beam. Still corrections are required for the residual field integrals originating mainly from the end fringe fields and the earth's magnetic field, since their impact on low energy electrons is significant. Contributing to the basic idea of making the undulator transparent to the electron beam, *i.e.* to have a net zero effect of the device on the beam, two pairs of correction coils at the ends and one pair along the entire length of the undulator have been mounted on the device. The power supplies for the four correction coils (upstream vertical, upstream horizontal, earth-field vertical, earth-field horizontal) have rating of 2A/75V according to the requirements. The defocusing effect of undulator due

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to the finite size of magnets (Fig. 7) is considerably high in case of the low energy electron beam as in the case of DLS where γ ~ 8-16 [5]. This defocusing effect will be taken care by implementation of an additional pair of correction coils along the length of the undulator. These coils will be mounted on the top and bottom of the vacuum chamber with the current flowing in the same direction. The field integral corresponding to the coil having one turn and 1 A current over the complete length of undulator has been shown in Fig. 8. This suggests that the coil of around 80 A of current (eight turns of copper wire with 10 A per turn) should be sufficient to compensate for the effect due to the transverse roll-off on the electron beam [5].

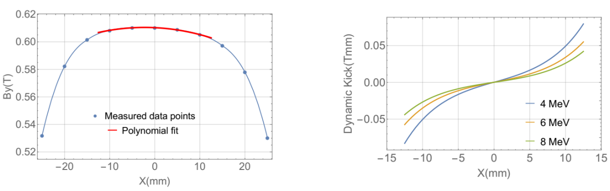

Figure 7: U48 Transverse field roll-off (left) and the dynamic kick [Tmm] introduced in the electron beam of three different energies over one undulator period (right).

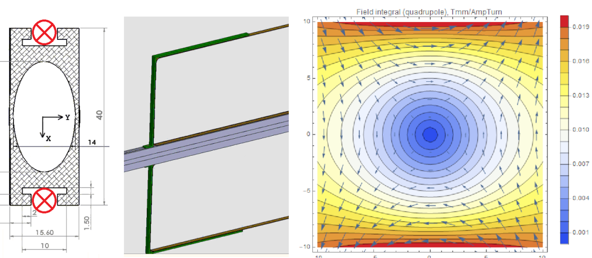

Figure 8: Two current carrying coils mounted on the vacuum chamber (left and middle) and the quadrupole field integral (right) produced by coil consisting of one turn with 1 A current.

FABRICATION OF VACUUM CHAMBER

The vacuum chamber for the undulator has been designed and fabricated at DESY. An elliptical inner aperture with a cross section of 14 x 25 mm^2 had been defined as required for the beam to stay-clear (Fig. 8). The outer dimensions are 15.2 x 40 mm^2 (horiz. x vertical) with T-grooves at the sides for a simple mount of the chamber support. The 2500 mm long profile has been extruded from aluminium alloy EN-AW 6060. For the chamber ends, a special transition piece made from AlMgSi0.5 has been used, which had been friction-welded to non-magnetic stainless steel 1.4429 ESU according to the DESY specifications. The flanges were machined from this material and finally welded to the aluminum profile.

CONTROL SYSTEM OF UNDULATOR AND LIMIT SWITCHES

The control system for the undulator is based on a real-time system running a software PLC and NC in a Windows environment. The NC controls the servomotor for the gap drive either using the motor encoder or the two additional linear encoders at each end of the magnet girders as feed-back. It also provides software limits for the gap motion and handles the first stage of hardware limit switches set 0.1 mm beyond the software limits. A second stage of limit switches cuts off the power from the drive, in case the gap position shall exceed the first stage by another 0.1 mm. As an extra layer of safety, in addition to the limit switches on the axes of the drive trains, there is also a set of switches mounted on the magnet girders getting activated in case, they approach the vacuum chamber. The PLC provides a GUI for commissioning, handles the communication with other control systems and set the currents for the correction coils.

CURRENT STATUS OF DEVICE AND TASKS TO BE ACCOMPOLISHED

The measurements and refurbishment work of the undulator U48 had been completed in the first quarter of 2020. U48 has been shipped to New Delhi in December, 2020 and is now at its position in the clean room of DLS. It is planned to perform stretched wire measurements at IUAC and to update the current tables for the correction coils. After the alignment of the device along with the vacuum chamber, the mounting of correction coils for defocusing effects will be done.

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